

EMI Considerations Designing DDX[®] Amplifiers

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Abstract

Contrary to popular belief, meeting EMI regulations with digital PWM switching amplifiers is not black art. Switch mode power supplies have been doing it for years. What is required is an understanding of the sources of noise and the hidden circuit paths that allow it to escape to the environment. In most cases it is not the actual PWM output that is the culprit but rather things that are already familiar to engineers designing consumer digital audio equipment; power supply currents and the clock signals used in all digital circuits. This application note discusses signals that create emissions from a DDX amplifier circuit and effective methods of identifying and suppressing these emissions. Using the guidelines presented in this application note an EB-2060S evaluation board was modified and demonstrated to pass Class B emissions requirements.

Introduction

When designing products utilizing digital signal processing or digital signals in general, audio or otherwise, attention must be paid to meeting Electromagnetic Interference, (EMI), regulatory requirements for different types of equipment. The importance of meeting these standards is obvious, in countries where EMI regulations are in force, using or selling a non-compliant product is not permitted. In this application note major regulatory requirements are reviewed, as are the types of noise that cause problems. Methods of identifying and suppressing emissions will be discussed and a modified DDX evaluation board is shown to pass Class B requirements without needing to be enclosed in a chassis.

Background

EMI Regulations and Measurements

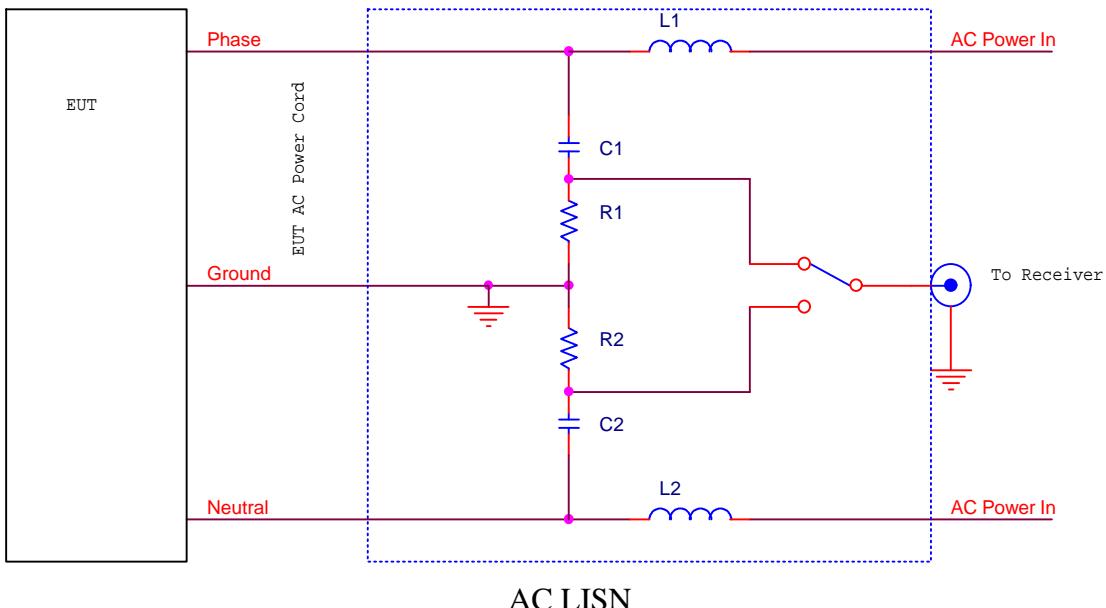
DDX amplifiers, are for the purpose of EMI regulations, considered Information Technology Equipment, ITE, as they receive, process and use digital data. The major standards are FCC Part 15, subpart B, in the US, EN55022 in Europe, and VCCI in Japan. At the time this application note was written, meeting the most stringent requirements of these standards covered the requirements of most countries, however, the manufacturer is responsible to meet the requirements of any country that your product will be sold or used in at the time your product is manufactured. Always check for the most current standards as regulations are subject to change.

This application note does not cover the methods or requirements of setting up a test facility to guarantee measurements can be made to the accuracy required for product approval, but is intended to show methods of discovering the areas that cause emissions and address typical solutions when developing products with DDX technology. For product approval, measurement of the emissions should be made at a facility that is certified to be in compliance with the criteria established by the relevant regulations and agencies. Certification is generally an indication of traceable calibration and measurement repeatability to recognized standards. Repeatability of measurements is key to demonstrating a product meets standards.

What exactly is measured? Two types of emissions are of concern; Conducted Emissions is the radio frequency energy that a product transmits along its power cord to the AC Mains, (also DC Mains in some countries), and Radiated Emissions is the radio frequency energy transmitted by the product into the air.

Conducted Emissions and Limits

Conducted emissions are measured as a voltage, expressed in dB μ V, using a line impedance stabilization network, LISN, and a measurement receiver, typically a spectrum analyzer, connected to the LISN's output port. A typical LISN schematic is shown in Figure 1. Its function is to supply a stable 50 ohm load impedance for the noise signals on the equipment under test, (EUT), power cord. A commercially available LISN and an AC line conditioner are recommended for development work.



Conducted emission limits for the US and Europe are given in the tables below.

Table 1, EN55022 Class B Conducted Emissions Limit

Frequency	Quasi-Peak Limit	Average Limit
0.15 to 0.5 MHz	66 dB μ V to 56 dB μ V	56 dB μ V to 46 dB μ V
0.5 to 5 MHz	56 dB μ V	46 dB μ V
5 to 30 MHz	60 dB μ V	50 dB μ V

Note that the stricter limit applies at the frequency transition points.

Table 2, FCC Class B Conducted Emission Limit

Frequency	Quasi-Peak Limit
0.45 to 30 MHz	48 dB μ V

A comparison shows that the FCC limits for conducted emissions are stricter than EN55022 limits between 450KHz and 30MHz but that EN55022 extends down to 150KHz where the FCC has no specification. When designing for conducted emission the goal should be to meet both resulting in the following.

Table 3, Design Specification for Conducted Emissions Limit

Frequency	Quasi-Peak Limit	Average Limit
0.15 to 0.45 MHz	66 dB μ V to 48 dB μ V	56 dB μ V to 38 dB μ V
0.45 to 30MHz	48 dB μ V	38 dB μ V

Average measurement is the typical mean value of a waveform whereas quasi-peak better represents the envelope of a waveform and detects short duration higher energy signals better than the average measurement. The spectrum analyzer chosen for development work ideally should be capable of both but in most cases an average responding instrument will be sufficient. Bandwidth up to 1GHz is desirable, as it will cover the radiated emissions range for DDX amplifiers as well.

A third item, an inductive current clamp is required for development work. It is useful for identifying the frequencies of currents being conducted by wires inside or outside the product and determining in a relative manner the effectiveness of the applied suppression techniques. This can be of either the passive or active variety but should be for 50 ohm termination to be consistent with input impedance of most spectrum analyzers.

Radiated Emissions and Limits

Radiated emissions are measured as electric field strength, expressed as dB μ V/m, by an antenna at a test distance of 10 meters from the EUT. A 3 meter distance is sometimes used to distinguish the emitted signal if a background signal is very strong, note that 3 meter testing is not accepted by all standards. This measurement is done with the EUT mounted on a non-conductive table at a height of 0.8 meter, the antenna is mounted such that it can be raised or lowered from 1 to 4 meters and rotated so that it can be set to measure the maximum signal emitted from the EUT. Both the EUT and receiving antenna are mounted over the same ground plane of metal sheeting or screening to permit additional EUT signals to be reflected to the antenna. The antenna and receiving system must be calibrated and correction factors applied to the raw measurement data to compensate for signal loss in the antenna and interconnect cable. At a test facility this test can typically run six hours or more as both the EUT and antenna must be rotated and moved in height to ensure that the maximum signal is being received in each scanned frequency range.

Table 4, Radiated emission limits for the US and Europe

Frequency (MHz)	FCC Class B Quasi-Peak (dB μ V/m)		EN55022 Class B Quasi-Peak (dB μ V/m)	
	3meter	10meter	3meter	10meter
30 to 88	40	30	40	30
88 to 216	44	33	40	30
216 to 230	46	36	40	30
230 to 960	46	36	47	37
960 to 1000	54	44	47	37

Note that as DDX amplifiers use less than a 108MHz clock, the maximum frequency subject to examination is 1GHz.

Again as for the conducted emissions a design specification for the strictest requirements can be generated.

Table 5, Design Specification for DDX amplifier radiated emissions

Frequency (MHz)	Class B Quasi-Peak (dB μ V/m)	
	3meters	10meters
30 to 88	40	30
88 to 216	40	30
216 to 230	40	30
230 to 960	46	36
960 to 1000	47	37

As with the conducted emissions the stricter limit applies at a transition frequency. Note also that a 2 dB μ V/m margin should be allowed to account for measurement repeatability.

Clearly it is much more difficult to replicate the radiated emissions test set up, primarily due to space constraints and the need to be away from interfering background signals. For development purposes both the inductive current clamp, mentioned for conducted emissions, and a near field probe kit are used to determine the frequencies that are emitted and again in a relative manner the effectiveness of the suppression technique. Near field probe kits are available commercially and are offered as both active and passive devices, again 50 ohm termination will be required to match the spectrum analyzer input impedance.

Near field probes are usually constructed to detect either magnetic fields or electric fields while rejecting the other. Magnetic probes are essentially loop antennas made from a single turn of semi-rigid coax cable and electric field probes are made from a stub of semi-rigid coax cable. It is possible to construct near field probes but the commercial variety typically are more durable and come with sensitivity curves similar to antenna correction factors. These probes are connected to the spectrum analyzer and brought into close proximity to the circuit in order to determine both the frequency content and type of emission being radiated.

Sources of Emissions (Noise), and General Suppression Methods

As previously discussed there are two types of emissions that are of concern, conducted and radiated. What is most important in suppressing these emissions is to understand how they are generated and to identify the source. Suppression of EMI is most effective when applied at the source. A good board layout is the first step to minimizing emissions.

Noise can be classified into two types according to the mode of conduction, Differential Mode Noise and Common Mode Noise.

Differential Mode Noise

Differential mode noise is conducted on a pair of signal lines or on a power line and ground in opposite directions to each other. This is represented as normal current flow in a system and is shown in Figure 2 below.

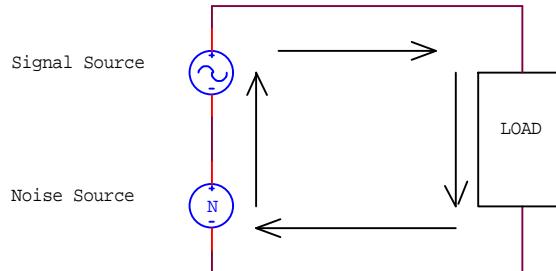


Figure 2
Differential mode noise

The Noise Source represents the high frequency current generated by the switching of digital circuits, i.e. the emission generator; and the Signal Source can represent either a power source or information signal source, i.e. the desired signal. The load can represent a digital IC load or other active device on a power supply or a circuit load, like a loudspeaker, depending on the function of the Signal Source.

Differential noise can be considered a 'conducted emission' in that the unwanted signal is conducted between the Signal Source and the Load or between the Load and Signal Source depending on which is generating the noise. It only becomes a conducted emission from a regulatory sense when the Signal Source is the AC Mains and the Load is the EUT with the Load generating the noise.

However, it is possible for this 'conducted emission', generated by a products internal circuitry, to become a 'real', in the regulatory sense, radiated emission. Remember that any changing current generates a magnetic field, H field, around the wire carrying it, this H field can radiate directly or induce currents in nearby circuits that will carry the noise to other places in the product. Laying out circuit boards such that the physical conductors carrying the noise current in opposite directions are close together can minimize this. Each conductor will generate an equal but opposite H field resulting in a net H field of zero. This especially applies to the power bus structure supplying the circuit's active devices and to the switching output of the amplifier power stage where the 'noise' currents are actually required for proper operation of the circuit. These traces should be kept as short as practical and their high frequency impedance minimized as any differential voltage will also generate an electric field, E field, between points in the circuit. Again the E field can either radiate directly or couple to other circuits.

Design Considerations

Consider the case of the power supply to the amplifier power output stage. The power output stage draws large peak current during the switch transitions resulting in a very high change in current during a very short time. This current, if allowed to circulate as shown in Figure 2, will result in a large radiated signal from both E and H fields; fortunately good layout and circuit bypassing are effective at reducing the emissions from this necessary

current flow. High frequency bypass capacitors, such as ceramic or tantalum dielectric, should be placed as close to the power device as practical, this will constrain the majority of high frequency current flow to the immediate area of the bypass capacitors and the power output stage as shown in Figure 3, note that these are in addition to the large bypass capacitors required for the lower audio frequencies.

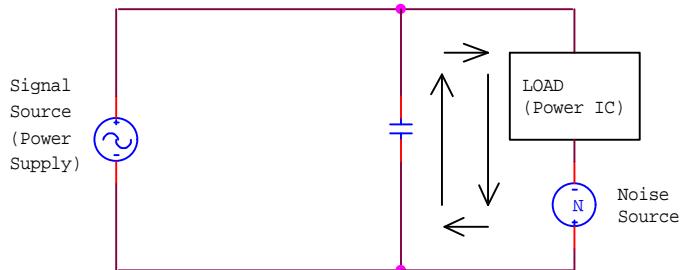


Figure 3
Load Bypassing

Power supply lines should be laid out so that supply and return lines run together as previously mentioned. These two items, properly applied to all active devices, will significantly reduce the area this noise signal travels around and subsequently the associated emissions. A ground plane is strongly recommended for DDX amplifier applications for both EMI and Thermal considerations.

When using a ground plane in high frequency applications care must be taken to understand the impedance and current flow in the actual circuit path. As an example, Figure 4 shows a ground plane with two signal trace routings. Trace A is the most direct path to the load from the perspective of the source but passes over a void in the ground plane. This forces the return current to flow around the void to follow the path of least resistance back to the source. At DC this would not be an issue, however at high frequencies a radiating loop antenna is formed and circuit inductance is increased. Trace B offers the lowest impedance at high frequency as the conductors run together minimizing circuit inductance. It also produces the desired field cancellation.

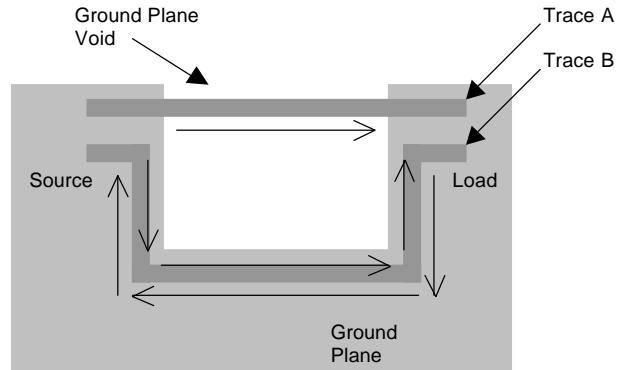


Figure 4

All digital signals contain high frequency components due to their fast rise and fall times. As good practice do not allow digital signals or power traces to digital devices to cross a void in a ground plane. Sometimes it is not possible to avoid this or it gets overlooked during layout. In those cases it may be necessary to increase the circuit impedance at the noise frequency to significantly reduce the noise current. Figure 5 shows a representation of this. The inductor can be a real physical inductor or can represent a ferrite bead. Ferrite beads increase circuit impedance by dissipating energy as heat and so act primarily as resistive components in the circuit. They are generally only effective under low bias current conditions for differential mode noise as their impedance can be significantly reduced with increasing bias current. Typically the use of ferrite beads is limited to signal levels for reducing differential mode noise and physical inductors or 'chokes' are applied to power bus signals. The capacitor shown in Figure 5 is generally a real physical component for power circuits and is a stray capacitance when ferrite beads are applied. In either case the principle of reducing the loop radiating area applies.

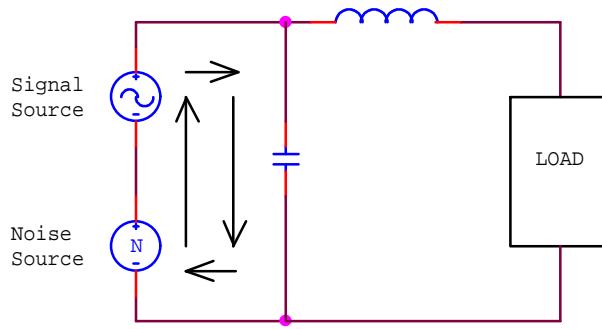


Figure 5
Differential noise suppression

Common Mode Noise

Common mode noise is conducted generally on a pair or group of signal lines or on power lines in the same direction. This is represented in Figure 6.

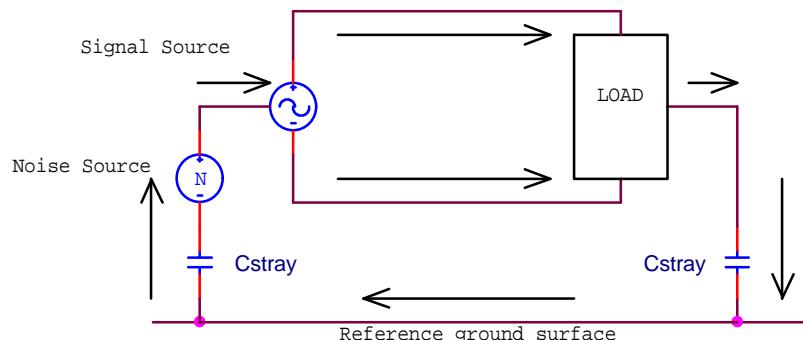


Figure 6
Common mode noise

As shown in Figure 6, common mode noise is similar to differential mode noise in that current flows in a loop. This loop is again the emissions radiator. What is different is that the return conductor, the reference ground surface, is not always as easy to clearly identify. For most electronic products the metal chassis becomes one, fortunately it is also a very good shield for most internally generated emissions. An example of this would be a digital clock line that goes to an expansion header but is unconnected to other circuitry. The return path for this clock signal is now through stray capacitance to the chassis back to its source. Signals such as these can radiate internally and appear at multiple places in the product, thus the importance of controlling EMI at its source, one suppressor is better than many.

Design Considerations

More common mode emission problems tend to appear at the interfaces of products where cabling enters or leaves the chassis. Generally coupling is due to pickup of internal emissions or from board conductors to signal paths that lead outside the chassis. These signals can have the earth itself, coupled through stray capacitance, as the return path. A good example to avoid in DDX amplifiers is power supply traces to the DDX power output devices should not run under, or be made into a plane layer under the audio output filter components. This will cause noise to be coupled to inductors or traces that then connect to the outside world after the PWM signal filter resulting in a radiated emission from common mode noise on the speaker lines.

Fortunately common mode filtering is effective and easy to apply. Figure 7 shows the use of a common mode 'choke', essentially a ferrite core transformer wound to induce opposing currents in the opposite winding to cancel the common mode currents. Ferrite beads are also extremely effective in this application, as the net field due to the differential signal current flow is zero they do not suffer from impedance decrease due to a bias current as a bead around a single wire would. This allows ferrite clamps to be used on multi-conductor cables as well. The transformer principle applies to beads as a few turns can be made on a bead core to increase its loss impedance. Generally frequency determines the choice of a common mode bead or common mode choke as the inter-winding capacitance of multiple turns limits the loss at higher frequencies and they are sometimes both used to fully cover a broad frequency emission range.

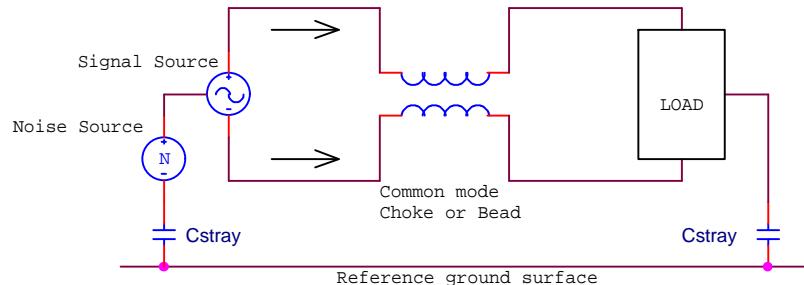


Figure 7
Common mode suppression with ferrites

Another effective method of suppressing common mode noise, particularly where cables enter or exit a product is to use capacitors to couple the common mode noise to the product chassis. This is represented in Figure 8. The noise is then able to couple back to the source and remain inside the chassis. A separate interface ground is typically used on a PCB to allow a single point connection to chassis or circuit ground of multiple bypass capacitors at an I/O interface area. It is also possible to combine choke and capacitor techniques for EMI filtering.

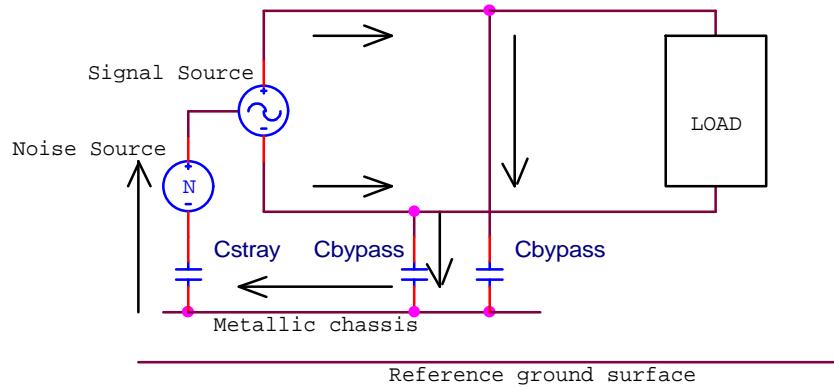


Figure 8
Common mode suppression with capacitors

Finding the Noise Sources

The time to look for noise sources is at the start of a design. Identify those signals that can potentially cause problems with conducted or radiated emissions. For a typical DDX amplifier these signals will be power supply distribution, clocks, the PWM output and drive circuits and to a lesser extent general logic signals. Pay close attention to the power supply bypassing and the PCB and chassis layout keeping in mind how differential and common mode noise becomes a radiated or conducted emission. Missing this step can result in the need for excessive suppression components and methods or in the worst case having to re-spin the design.

The method of finding the residual noise sources is straightforward, after examining the design and layout there should be some expectation of what to look for and where.

The product must be configured as the final consumer will use it, that is as generally hooked up and operating in a typical fashion. Before going for verification test a pre-scan should be performed to identify emissions and steps taken to determine where and how to suppress them most effectively. Some of the steps can be implemented directly or planned to be implemented at the test site if required, which to do becomes a matter of experience. In any event you should arrive at the test site with a plan based on information from the pre-scan. The scan needs to be performed with sufficient resolution to determine a signal from a group of signals, for a DDX amplifier a detection bandwidth of 120 KHz is generally adequate for radiated pre-scans. When doing a pre-scan outside of a screen room the background level being picked up for each measurement should be determined with the EUT switched off.

Using the spectrum analyzer and the inductive current clamp determine the signal components that are being conducted out of the EUT on its cables both for common mode and differential signals, record frequency and amplitude for each significant signal. Use the current clamp to determine the common mode signal on the AC power cord and the LISN to determine what is conducted on each wire. Suppression of line-conducted emissions will likely use a line choke in combination with a capacitive bypass to chassis filtering due to the lower frequencies; provisions for this should be made at the design stage. Use knowledge of the system design to determine if the frequencies are fundamentals of the system or harmonics. Do not be surprised to see very high order harmonics; the small geometries on PCB's do not make efficient antennas at low frequencies. Next take the most sensitive near field loop probe, H field, and bring it near enough to the EUT to start seeing a signal, as an emission can be radiated in any direction the probe should scan a spherical radius about the EUT. Identify these far field signals first as they are more likely to cause compliance issues. The ones closer to the EUT are likely related and will be suppressed along with them. Find the strongest signal and note the distance and direction from the EUT as well as the frequency and amplitude. Switch to progressively less sensitive probes and follow the line of maximum emission to identify where it is coming from on the EUT. Trace the emission to its source inside the unit using the smallest loop or small E field probe and determine which method of suppression can be applied. Apply the suppression and repeat the measurement to determine its relative effectiveness. If no change is apparent then the source was not properly identified. If the emission is eliminated or significantly reduced then it was the only or main source. In addition to the frequency information from the spectrum analyzer, a time domain waveform of the radiated signal should be viewed either by demodulating the signal with the analyzer or by hooking the probe to an oscilloscope to gain more insight into the offending waveform.

More extensive information on determining the sources and types of emissions can generally be found in the near field probe manufacturers users manual.

Conclusion

In summary, during the product design phase minimize the problems you know about. Pre-scan in the lab to understand what remains and determine methods to suppress it. Go to the verification test site prepared to implement several techniques as schedule and budget requirements generally have a role in determining the 'best' solution. Remember that the test conditions of pre-scan and verification are usually not the same, frequencies that had not been identified as problems can appear, and vice versa. Be ready to identify and suppress new emission sources at the verification site. If the attempt to reduce an emission fails it is due to one of four reasons,

1. The diagnosis of the source is wrong.
2. The suppression technique is not correct for the identified source.
3. The suppression technique is not properly applied.
4. A second source at the same frequency or other outside factor is involved.

Do not leave the verification site without gathering as much information as possible about a failure; it will be invaluable back in the lab.

Regulatory requirements have been reviewed and methods of identifying and suppressing emissions relevant to DDX amplifiers have been offered that will be effective in meeting those requirements. A specific example of configuring a DDX amplifier is given in Appendix A. Using the techniques and methods presented in this application note the Apogee EB-2060S stereo evaluation board, a Class A laboratory device, was modified to meet Class B limits for a typical application without benefit of a shielding chassis.

Appendix B shows scanned images of the Certificate of Compliance, report highlights and photographs of the EUT. Appendix C is a checklist of do's and don'ts for quick reference when designing your system. Appendix D shows schematic circuit examples of typical suppression components applied at PCB interfaces.

Additional information on EMI suppression is available from the ferrite and suppression component manufacturers listed in the References section.

Appendices

Appendix A

Modifications to EB-2060S to be Class B compliant

The EB-2060S evaluation board was tested on 5/17/01 as an unenclosed board and passed radiated emissions at 10 meters. A simple open frame linear power supply was constructed and used and the 5-volt switching regulator supplied on the stock EB-2060S evaluation boards was replaced with a linear regulator. This was to insure that switch mode regulator and power supply emissions did not obscure EMI issues related to DDX amplifier components. The optical input was used also to not obscure EMI issues. The input signal was -14 dBFS pink noise with +12 dB of gain applied to replicate a typical full power music output at approx. 9Wrms/Ch.

No modifications were made during the radiated test, but pre verification testing the board was modified based on the pre-scan activity as follows:

Filtering components added to inputs or outputs;

Speaker leads;

-- Modified to include common-mode beads, Steward P/N CM3322X630R-00, between the filter output and speaker, (8 ohm loads). These were mounted on the PCB and filter a common mode current from the speaker leads.

Power leads from EB-2060S to open frame linear supply,

-- A Fair-Rite 2673002402 shield bead with 6 turns of #24 wire, wound common mode, on the power input wires, this was to address low frequency common mode conducted emissions that radiated off the DC power lines to the power supply, it is unlikely this bead would be required if the power supply and amplifier share the same PCB. A Fair-Rite 2643002402 shield bead with 3 turns of #24 wire, wound common mode, was installed between the 2200uf bypass capacitor and the power input connector, for the high frequency emissions. Note that these beads appear in series and each covers a different frequency band. Using type 31 material from Fair-rite would accomplish the function of both with a single bead but was not available at the time. Also note that the Steward P/N CM3322X630R-00 is effectively the same as a Fair-Rite 2643002402 shield bead with 3 turns of #24 wire but is easier to use, as it is a surface mount component. More information on these beads and ferrite material characteristics can be found at the respective manufacturers websites, www.steward.com and www.fair-rite.com.

On the evaluation board connectors J6 and J7 are expansion headers to allow use of other IIS sources for development purposes, in a real application they would not be present. All traces from these headers were cut at the signal source on the PCB and grounded to prevent them from acting as antennas for the 256*fs clock recovered from the S/PDIF receiver.

A ferrite bead, Fair-rite 2508051217Z0, was added to the 256*fs MCLK output of the S/PDIF receiver to damp a differential mode emission that coupled common mode to the power supply and speaker leads. The emission is due to the MCLK line crossing several ground plane voids.

During the conducted test a 0.1uf capacitor was added across the rectifier bridge/transformer windings to tame the diode commutation spikes. This is a typical linear power supply that one would use in a stereo powered speaker application. The transformer winding was rated at 53VA and supplied 28VDC to the evaluation board during operation. Full bridge rectification was used and filtered at the power supply with a 4700uf cap. The transformer core and mounting were connected to earth ground by the third prong of the power cord. The circuit ground was connected to the earth ground by a 2200pf coupling capacitor.

During the pre-scan the conducted emissions were found to be due to primarily common mode conduction of the output PWM frequency and required the installation of a common mode choke. The power line filter use was a Murata PLY10A2821R2R03B1 combination differential/common mode line choke. Specifications are available at www.murata.com.

Appendix B

Verification Test Report

Excerpts from the EB-2060S evaluation board verification test report by permission of Integrity Design and Test Services, Inc.

 <p>Integrity Design & Test Services An Entela, Inc. Company</p>					
<h3><i>Certificate of Compliance</i></h3>					
<p>The following product was found to comply with the requirement stated below when tested in accordance with the test procedures described in the accompanying test/measurement report. Reference report number 66920.e1</p>					
Manufacturer:	Apogee Technology, Inc. 129 Morgan Drive Norwood, MA 02062				
Product Name:	DDX Stereo Evaluation Board				
Requirement:	FCC Part 15, EN55022: 1998, VCCI, AS/NZS 3548 Class B				
<p>Approved By:</p> <table border="1" style="width: 100%; border-collapse: collapse;"><tr><td style="width: 50%; padding: 5px;">Michael Koffink NVLAP Signatory</td><td style="width: 50%; padding: 5px; text-align: center;"></td></tr><tr><td style="width: 50%; padding: 5px;">Date</td><td style="width: 50%; padding: 5px; text-align: center;">6/19/01</td></tr></table>		Michael Koffink NVLAP Signatory		Date	6/19/01
Michael Koffink NVLAP Signatory					
Date	6/19/01				
Remarks:	<p><i>Testing is performed using calibrated equipment traceable to the National Institute of Standards and Technology (NIST).</i></p> <p><i>This certificate is valid for products tested as described in the accompanying test report. Specific modifications necessary to meet the above requirement, recommended by Integrity Design & Test Services, Inc. are described therein.</i></p>				
<p><i>Integrity Design & Test Services, Inc. is accredited by the National Voluntary Laboratory Accreditation Program (NVLAP) for Electromagnetic Emissions Testing</i></p>					

2. Test Environment

2.1 EUT Description

Model number: EB-2060S

S/N: SN0006

Model name: DDX Stereo Evaluation Board

Description: The EUT is for evaluating the Apogee Technology, Inc. DDX Digital Audio Amplifier Chip Set, the DDX2000 processing IC and the DDX2060 power IC. It converts standard PCM audio data to a Pulse Width Modulated signal completely by digital means to reconstruct an audio signal with sufficient power to drive loudspeakers. Its intended environment is for laboratory evaluation use by manufacturers of consumer audio products who would then incorporate the DDX chip set into their products. This testing is intended to demonstrate that product that meets regulatory agency requirements can be produced with the DDX chip set.

2.1.1 System Operation

The system was configured in a typical operation. During testing, the EUT was connected to a portable CD by optical cable to SPDIF input. Test CD supplies -14 dBFS digitally generated pink noise to both channels of EUT. The linear power supply provides 28VDC under load to EUT, 30V with no load. The EUT provides +12dB of gain to the signal to simulate music played with full power. Outputs are loaded each with 8

2.1.2 Support Equipment:

Description	Manufacturer	Model Number	Serial Number
Portable CD Player w/ optical SPDIF cable	Sony	D-EJ815	Not Labeled
Linear Power Supply (open frame) 28VDC	Apogee Technology	Not Labeled	Not Labeled
8Ω 50W Resistive loads	Milwaukee	Not Labeled	Not Labeled

Cables

Qty	Description	Cable (Loopback/Open Ended/Connected?)	Unshielded/Shielded Type (Braided/Foil)	Shield Termination (360°/Drain)	Length (Meters)
1	AC Power Cord	Connected	Unshielded	N/A	1.3
1	Power, 16AWG	Connected	Unshielded	N/A	0.5
1	Optical SPDIF	Connected	Unshielded	N/A	1.3
2	Speaker, 16AWG	Connected	Unshielded	N/A	3

3.1.5 Results

The EB-2060S met the FCC and EN55022 Class B radiated emissions requirements when tested as described below. (See Appendix A for a complete listing of data points).

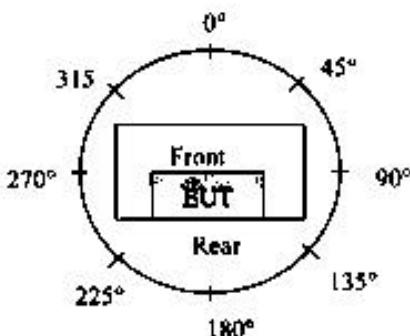
Worst case emissions measured:

Modifications	FCC Class B Radiated Emissions	EN55022, VCCI AS/NZS 3548 Class B Radiated Emissions
See Note (1)	Passed: -3.5 dB at 372.4 MHz Line Voltage: 120 VAC, 60 Hz See Table: A1 Azimuth Angle (see diagram below): 90° Antenna Height: 2 Meters Polarity: Horizontal	Passed: -2 dB at 214.4 MHz Line Voltage: 120 VAC, 60 Hz See Table: A1 Azimuth Angle (see diagram below): 270° Antenna Height: 1 Meters Polarity: Vertical

Notes

(1) Final scan. No modifications installed.

Azimuth Angle Diagram



The above results pertain only to the specific item submitted for testing, identified by the product's model and serial numbers.

3.2.5 Results

The EB-2060S met the FCC and EN55022 Class B conducted emissions requirements when tested as described below. (See Appendix A for a complete listing of data points).

Worst case emissions measured:

Modifications	FCC Class B Conducted Emissions	VCCI Class B Conducted Emissions	EN55022, AS/NZS 3548 Class B Conducted Emissions
See Note (1)	Passed: - 6.6dB at 0.7MHz Line Voltage: 120VAC, 60Hz See Table: A2	Passed: - 8.2dB at 0.15MHz Line Voltage: 120VAC, 60Hz See Table: A3	Passed: - 8.2dB at 0.15MHz Line Voltage: 120VAC, 60Hz See Table: A4

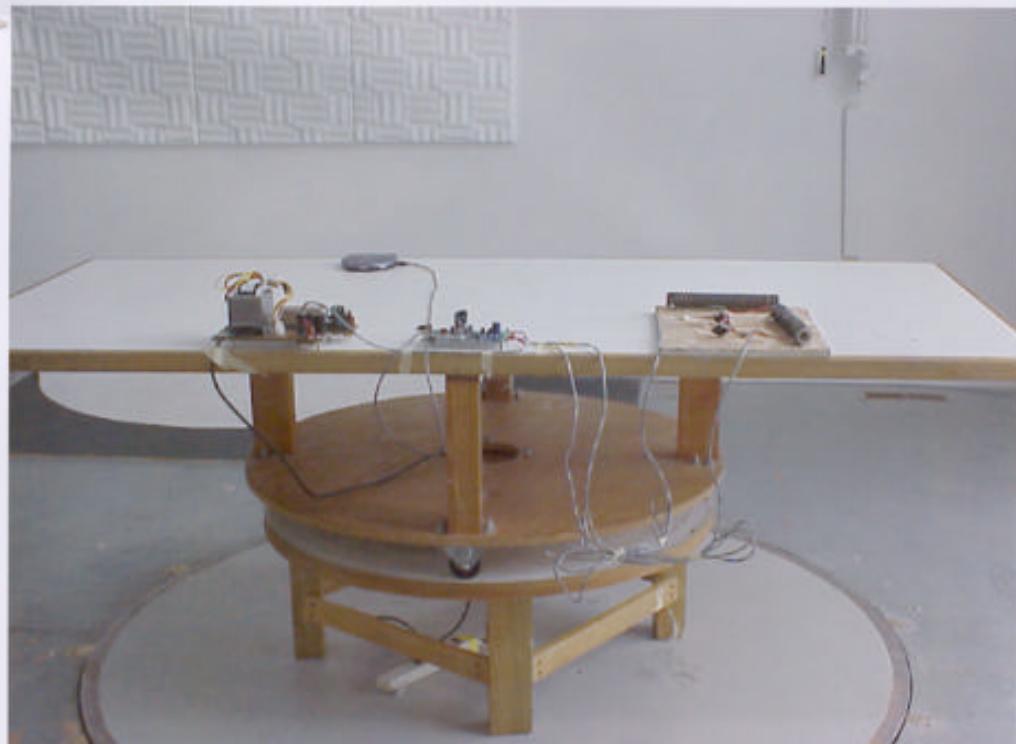
Notes

(1) Added missing 0.1 μ f rectifier suppression capacitor.

The above results pertain only to the specific item submitted for testing, identified by the product's model and serial numbers.

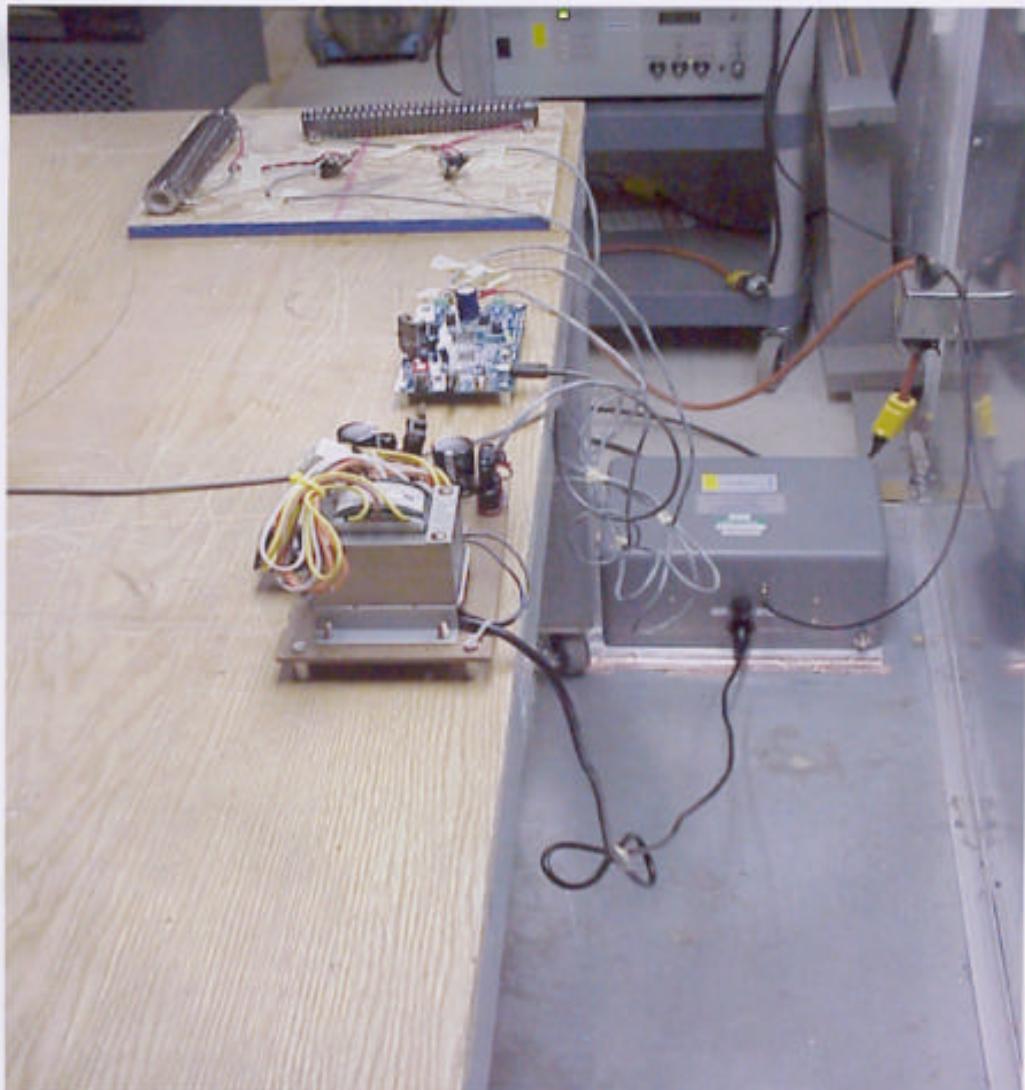
Configuration Photograph

Apogee Technology, Inc.
EB-2060S



Worst Case Radiated Emissions Test Configuration

Apogee Technology, Inc.
EB-2060S



Worst Case Conducted Emissions Test Configuration

Appendix C

Checklist of Do's and Don'ts

Before beginning the design

- Understand the requirements of the countries your product will be sold in.
- Be familiar with the operation of DDX amplifiers and the spectrum they generate, the PWM frequency and harmonics dominate conducted emissions and the master clock harmonics dominate radiated emissions.
- Be familiar with other digital components in your product, particularly switch mode power supplies.
- Understand the concepts of Differential and Common Mode Noise.
- Understand the techniques and components used to suppress emissions.
- Make sure you will have the proper equipment on hand for evaluating EMI and understand how to use it.
- Plan for pre-screening your product and make allowances for a second iteration.

During the design and prototyping

- Treat the product as a whole, the chassis design and board layouts must compliment each other to minimize emissions.
- Understand how and where current flows in your design and identify critical areas to layout first to minimize emissions.
- Make allowances for suppression components in critical areas, especially at I/O interfaces, it is easier to remove or leave out a component than to add one.
- Pay particular attention to power supply routing and bypassing, and to the routing of the PWM outputs and the filter layout. Current flowing out needs to return back on the same path.
- Use a ground plane, unbroken as possible, and keep connections short.
- Do not let digital signals cross a void in the ground plane, allow space for using a ferrite bead if you can't avoid it.
- Do not make unconnected stub traces on digital signal lines.
- Be aware and check for common mode coupling, do not route noisy signals where they would couple to traces or wires leading outside the chassis.
- Review the entire design before committing to hardware. A fresh set of eyes may catch something you have missed, even better if they have EMI experience.
- Pre-scan your PCB and product with near field probes; know what emits and how before the verification test.

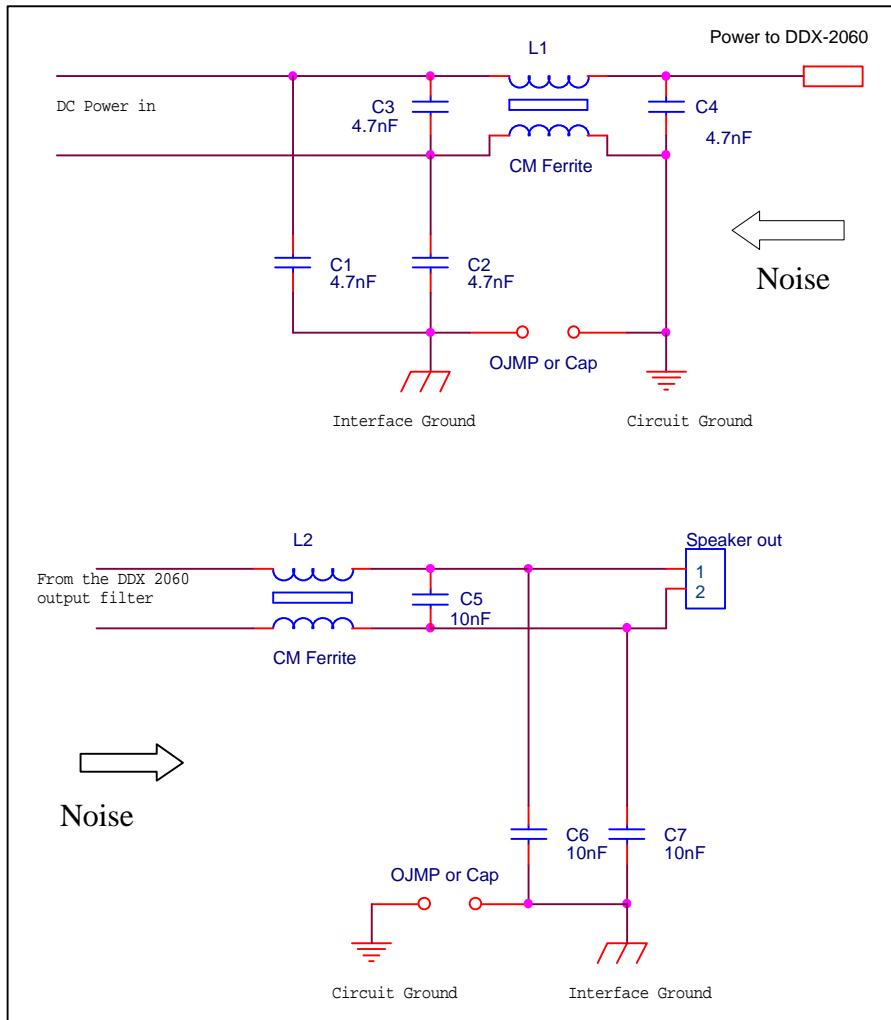
At the Test Site

- Look for the problems you know about, be ready with more than one method of suppressing an emission if possible.
- When you fail to suppress an emission get as much information at the test site as possible.

Appendix D

Schematic Examples of Suppression Components

This is an example of EMI filtering for DC Power and Speaker lines for a DDX amplifier. Generally all components will not be required in most cases, but is illustrative of typical methods of suppressing unwanted signals from conducting off a board. The combination of ferrites and capacitors produce simple RC filters. Note that different values of capacitance and types of ferrites will be required depending on the frequency to be filtered. Care must be taken to not run noisy signals under or near the input for the DC Power, or the output for the Speaker lines of these filters or noise can be coupled to wires leading off of the PCB nullifying any benefit of the filter. In some instances, such as prototyping, it is advantageous to have a separate interface ground to bypass to. This allows the 'Interface Ground' to be connected to either circuit ground or chassis ground in any manner, AC with a capacitor or DC with a zero ohm jumper, 0JMP. It also keeps normal circuit currents away from the I/O areas of the PCB.



Typically if the application has a chassis, and the power source is in the chassis, the DC Power input filter is not likely required. Its purpose is to prevent coupled noise from radiating off a connecting cable to the power supply. In that case, a similar filter will likely be used on the AC power line for conducted and radiated emissions. The frequency range of most common mode ferrites starts to become significant in the range of 10MHz up, below this frequency wound choke coils tend to be more effective.

References

EMC Test Systems, (1999). User's Manual, Near-Field Probe Set, Model 7405.

<http://www.fair-rite.com>, online product catalog, "Choosing Ferrite Materials".

<http://www.murata.com>, online product catalog.

<http://www.steward.com>, Application notes, "Use of Ferrites" and "EMI Testing".